ADVANCED PRODUCT DEVELOPMENT INTEGRATION ARCHITECTURE: AN OUT-OF-BOX SOLUTION TO SUPPORT DISTRIBUTED PRODUCTION NETWORKS

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ABSTRACT

This paper presents novel collaboration methods implemented using a centralised client/server product development integration architecture, and a decentralised peer-to-peer network for smaller and larger companies using *open source* solutions. The product development integration architecture has been developed for the integration of disparate technologies and software systems for the benefit of collaborative work teams in design and manufacturing. This will facilitate the communication of early deign and product development within a distributed and collaborative environment. The novelty of this work is the introduction of an 'out-of-box' concept which provides a standard framework and deploys this utilising a proprietary state-of-the-art Product Lifecycle Management System (PLM). The term 'out-of-box' means to modify the product development and business processes to suit the technologies rather than vice versa. The key business benefits of adopting such an approach are a rapidly reconfigurable network and minimal requirements for software customization to avoid systems instability.

KEYWORDS

Product Development Integration Architecture, Collaborative Networks, Product Lifecycle Management, Peer-to-Peer

1. INTRODUCTION

A major problem facing industry nowadays is the lack of use of current technologies into early design and manufacturing phases in collaboration and information distribution to support product development activities. Examples of these activities include manufacturing process planning, workflow analysis, knowledge management, product design, and process modelling. Furthermore, manufacturing processes display ever growing complexity and dynamic behaviour due to both increasing product complexity and distributive and collaborative engineering demands. In order to facilitate these criteria, advanced strategic corporate alliances must share knowledge, expertise and resources in an increasingly competitive global market. Furthermore, effective information and data sharing are directly linked to the competitiveness of an enterprise. Whether it is a single enterprise or a network of organisations, effective collaboration and data distribution is an important aspect. Collaboration systems represent a key tool fulfilling this need. This is particularly critical for smaller companies who find it difficult to meet the cost of these software systems. One example is the Product Lifecycle Management (PLM) system (CIMdata, 2002). PLM is an expensive system and mostly operated by large companies. Apart from the cost of the software system, there is an additional disadvantage for small and medium enterprises (SMEs) to collaborate with the Original Equipment Manufacturers (OEMs): SMEs have to store all relevant product development data within the PLM system deployed by the OEMs. The SMEs typically do not have the autonomy in such a restricted environment.

Due to rapid advances in Information and Communication Technologies (ICTs) new paradigms have been proposed to support distributed network environments. Among these are: Virtual Enterprise (Ettighoffer, 1992) Distributed and Re-configurable Enterprise (Gunasekaran, 1998) and, most recently, Cloutier et al (2001) introduced Networked Manufacturing Co-ordination and Vernadat, (2002) in Enterprise Integration architecture. All these paradigms have one thing in common; they all require highly trained and sophisticated skills to customize and integrate. Customization is often required to modify the software to suit the environmental needs. This may cause the system to be more unstable and difficult to maintain when it finally comes online. The maturity of web-based technologies and the availability of ‘off the shelf’ enterprise systems, this research has proposed a different approach: to deploy an 'out-of-box' solution for the integration of disparate software systems. The term 'out-of-box' means to modify the product development and business processes to suit the technologies rather than vice versa. The advantages of this approach are rapidly reconfigurable collaboration network and minimal requirements for system customization, thus avoiding instability that might result. As a consequence, this paper presents: (1) an advanced conceptual product development integration architecture which has been specifically developed for the integration of these disparate technologies for the benefit of collaborative work teams; and (2) to enable designers to use a seamlessly integrated interface to review, analyse and reuse engineering and manufacturing knowledge within the network of collaborating enterprises.

To verify and demonstrate the applications of 'out-of-box' solutions, this paper will focus on the principal hypothesis of bridging the discontinuity in the early stages of design where communicating concepts and potential manufacturing scenarios are critical. The collaborating designers are to be linked using internet-based PLM systems that incorporate techniques for design conceptualisation, aggregate factory modelling and manufacturing knowledge management (Maropoulos and Gao, 2001). In the remainder of the paper, the fundamental infrastructure of the product development integration architecture and its implementation issues are discussed. Two case studies are presented to verify and demonstrate 'out-of-box' solutions of a centralised and de-centralised networks configuration as proposed.

2. THE PRODUCT DEVELOPMENT INTEGRATION ARCHITECTURE

Figure 1 illustrates the integration environment which is distinguished into *three layers*. The first layer is the enterprise systems which consist of PLM, Enterprise Resource Planning (ERP) technologies and the Peer-to-Peer (P2P) framework (Bond, 2001). The second layer is the communication and data exchange mechanisms, i.e. JXTA (Juxtapose) (Gong, 2002), client/server and XML Parser (eXtensible Markup Language) (Holzner, 2001). The third layer consists of the Manufacturing and Design domains to support product development processes. The architecture uses a PLM system to address design collaboration. This out-of-box solution provides the functionality for different designers at different locations to access the same design concurrently. The architecture also supports STEP-based standards for geometric models. This standards-based collaboration can work dynamically in a global, distributed, and heterogeneous design environment. In addition, PLM offers *lifecycle management* and *version control* for the design and the ability to see the history or 'evolution' of a design through all its iterations.

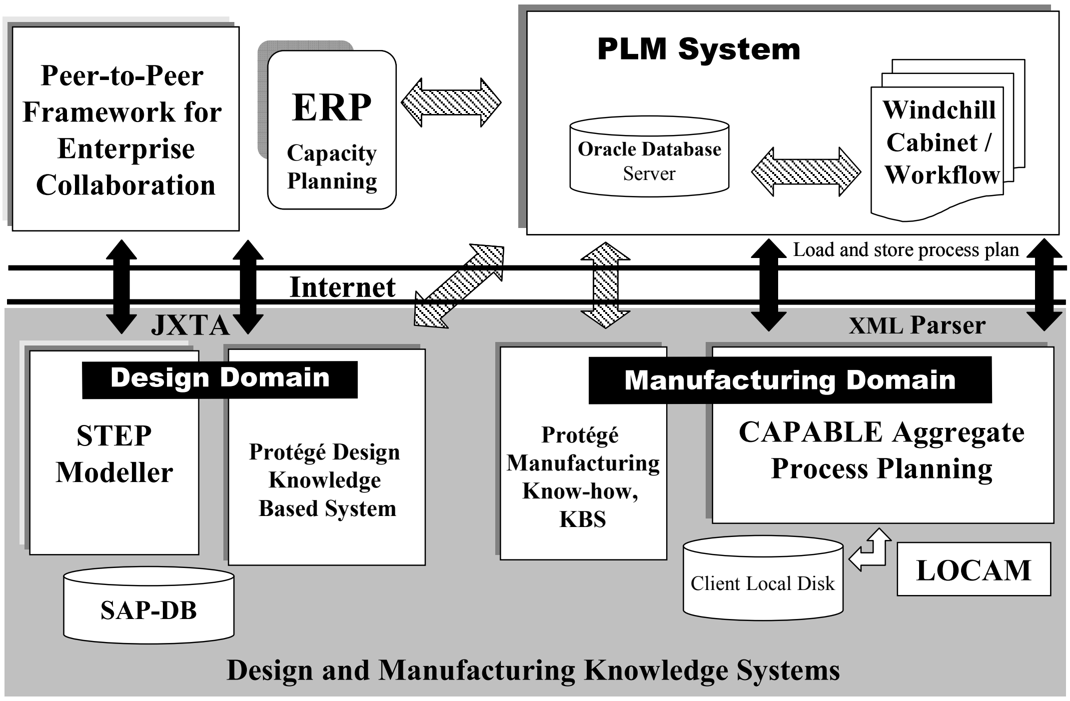


Figure 1: Overall System Integration Architecture in Product Development

An XML Parser is deployed as the interfacing medium between PLM and the Manufacturing and Design Domains for data interchange. This enables interchanging portions of XML documents while retaining the ability to parse them correctly and, as far as practicality is concerned, formatting, editing, and processing in useful ways (Holzner, 2001). JXTA is an *open source* communication protocol for P2P network connectivity (Cheung et al, 2004; Aziz et al, 2005). The manufacturing domain consists of a manufacturing knowledge-based system. LOCAM is a commercial process planning system for the detailed stages of product development which was not used due to the fact that this research has been focused on early design and development stages. Finally, the design domain consists of a STEP Modeller and Design Knowledge Based-System (Aziz et al, 2004).

P2P, a decentralised communication network, is used to enable such a hybrid integration approach. This is to enhance the integrity of knowledge and data sharing and the efficiency of network communication for collaboration of smaller companies within the supply network. The advantages offered by P2P applications are (i) no single point of failure, the network is alive as long as one peer is on-line, (ii) distributed sharing of node resources for storage and processing power, so the system becomes more powerful as more users attach, (iii) lower running cost due to the lack of high performance servers, as well as (iv) maintaining individual control of the shared knowledge. The objective of this research is to extend and further develop the product development integration architecture, which includes a new framework to explore alternative computing resources and network architectures in order to reduce cost as well as providing the autonomy for smaller companies to share information with larger collaborators.

Figure 2 illustrates a subset of the product development integration architecture. The main technologies used in the framework are the P2P decentralized network (Penserin et al, 2003) and open source workflows implemented with *RosettaNet* and *JXTA* (Gong, 2002) for network connectivity. One further aspect of P2P systems is to distribute the main costs of sharing data, computing power, network bandwidth and storage capacity (Bond, 2001). This is particularly suitable for SMEs without the need of powerful, expensive servers as well as providing autonomy in terms of data sharing with the PLM system used by the OEMs.

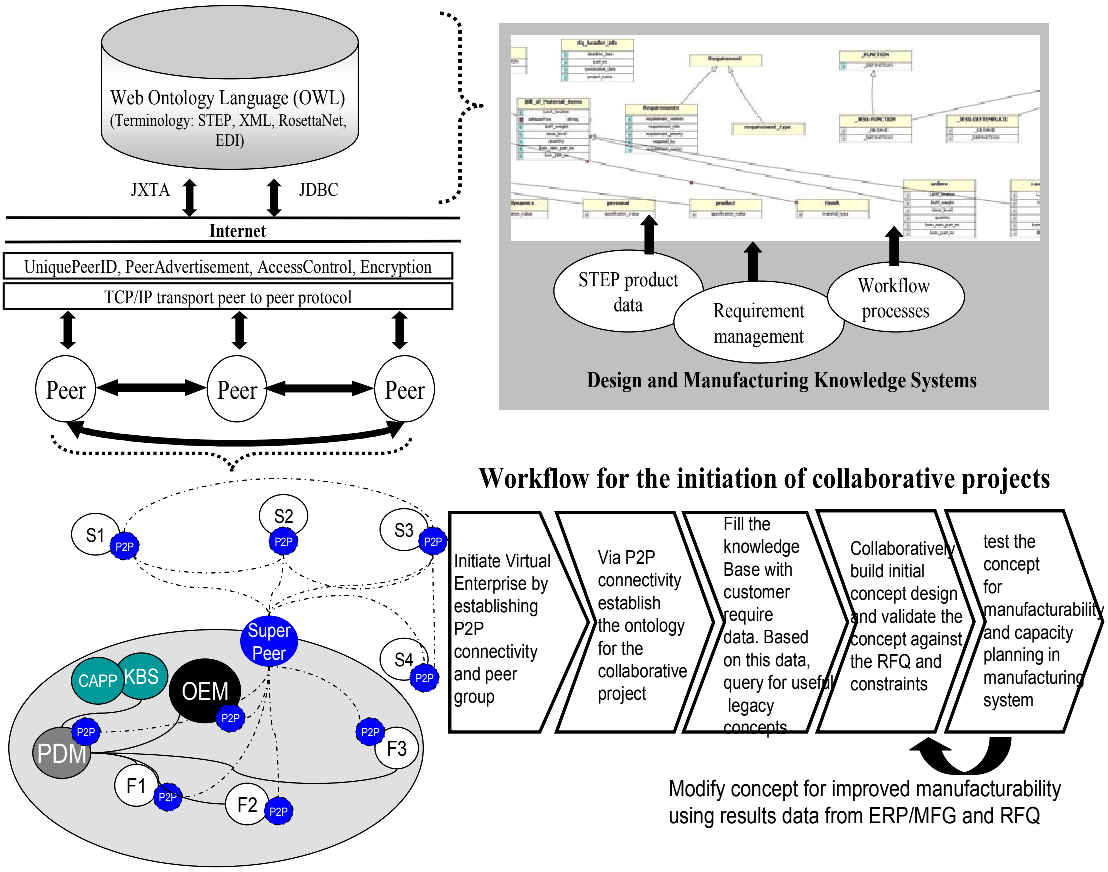


Figure 2: Overall Peer-to-Peer Framework for Enterprise Collaboration

One of the main applications of PLM systems is to control product development data more effectively by maintaining the data within a centralized network throughout its product lifecycle using the PLM's native *workflow* functions. Most mainstream PLM systems are operated in an inherent client/server paradigm which is complex to set up and requires a long period of time for customisation. However, it has been identified that *workflows* and any customisation carried out within a PLM system cannot be reused on another PLM system (Aziz et al, 2005). On the other hand, the *RosettaNet* standard (Yendluri, 2000), implemented in PLM systems, can decrease the amount of customisation needed, but not eliminate it, as *RosettaNet* only provides a subset of the messaging and data models of the inter-enterprise link.

3. IMPLEMENTATION ISSUES

3.1 Coordination of the Integration Architecture for Time-Dependent Components

The integration of distributed time dependent components requires a time synchronisation model. The time based element requires the recognition of the time-dependencies of activities within a distributed team that use the stored data and knowledge. In general, a PDM module of a PLM system comprises a "*Document Manager*" that contains a list of user defined *cabinets* to store data files, a "*Lifecycle*" function that defines the timing of the development stages and a "*Workflow*" function that determines what processes and interactions take place at each stage. Clearly, PLM can be used as a foundation for defining a time based integration wrapper as a time synchronisation model.

Figure 3 illustrates the coordination requirements for the design of a workflow, which can be classified into internal and external integration requirements (Becker et al, 2002). Lifecycle management is responsible to define the development stages from conception through design, engineering, manufacturing, use and maintenance to disposal. Networking allows all users to interact through Web services to enable the collaboration through the use of external and internal applications.

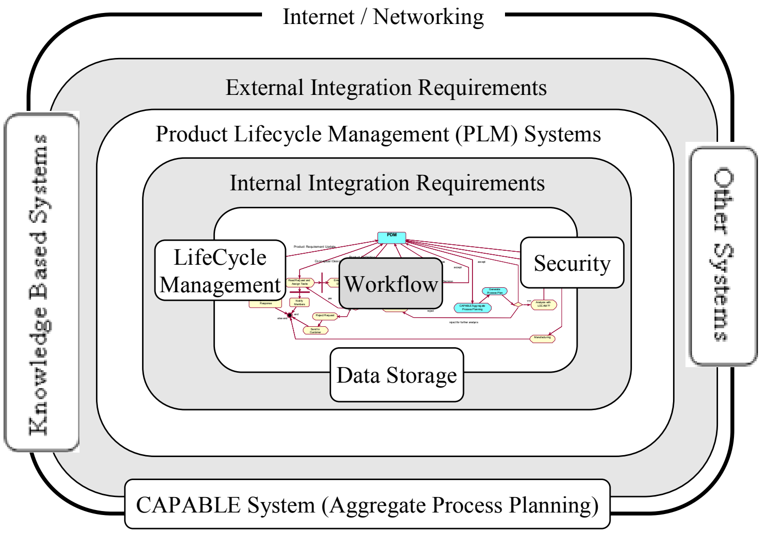


Figure 3: Coordination of Time dependent Components

Internal integration requirements concern those systems and functions which workflow applications need to connect to. For example, the internal functionality of a PLM system is life-cycle management, data storage and security. External integration requirements exist with regard to systems that either invoke the workflow system from the outside (embedded usage) or systems that are invoked by the workflow applications, for instance, the software systems such as the Knowledge-based system (Cheung et al, 2006) and the CAPABLE System (Maropoulos et al, 1998; Bramall et al, 2003). Since work coordination involves external networks and external applications, another issue that must be addressed is security on the public Internet (WWW). One major advantage of using PLM systems for Workflows is that they automate information flows between individuals carrying out business processes. It has two major implications for security:

i. The description of a workflow process explicitly states when each function is to be performed and by whom, therefore security specifications may be derived from such descriptions and translated into static role-based specifications, and

ii. The Workflow functions are to be operated via Web-browsers, thus individual security rules must be enforced.

A novel "Workflow Activity Task Controller" (WATC) methodology has been defined to implement the *time based integration wrapper* concept in the interactions between generic types of PDM, ERP, Knowledge Based and Process Planning systems and has been formalised in Unified Modelling Language (UML) as shown in figure 4. The implementation of WATC is centred on the lifecycle and workflow functionalities of the PDM system using web-based technologies such as XML and a Java-based XML parser. The core technologies behind WATC are methods to control the interactions of a PLM system, a Knowledge Based System and a Process Planning System. WATC sequences early design activities including *concept definition*, *design development*, *manufacturing knowledge sharing* and *automated aggregate plan* generation. WATC currently supports the following five early design stages.

(i) Receive/understand customer product request and formalise design specification,

(ii) Generation of conceptual design by the Product Development Team,

(iii) Distributed review of conceptual model and addition of manufacturing knowledge and constraints,

(iv) Deployment of capability analysis (Baker and Maropoulos 1998) for the prioritisation of product development tasks, and

(v) Generation of aggregate process plans (routings) and integrated capacity planning.

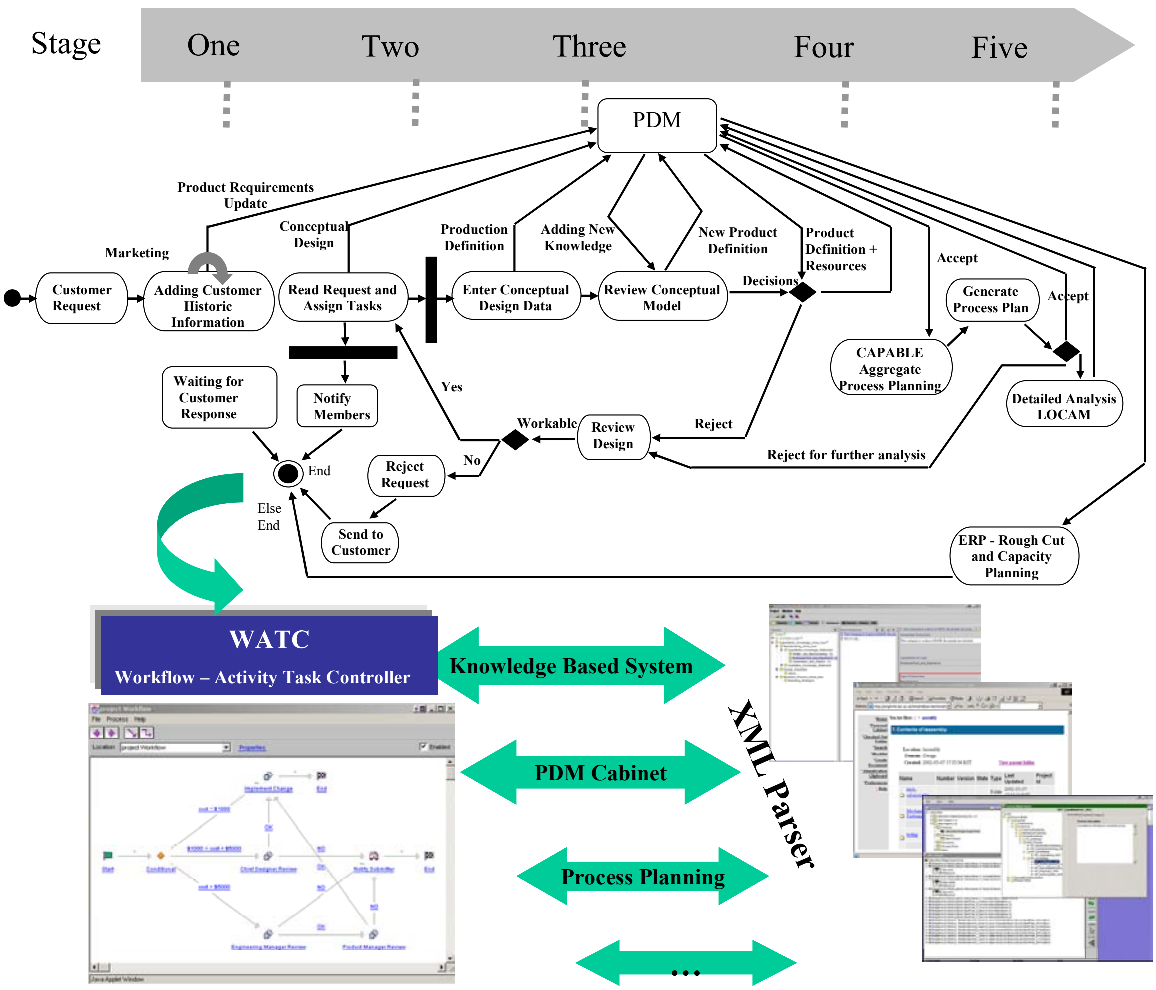


Figure 4: Time Dependency Scenario using WATC Concept

The workflow starts with the customer's request for a new product or a change to an existing product. The initial stage is adding customer historical information such as previous product specifications, customer buying experience and relationships. This can be done by invoking a knowledge-based system. The knowledge-based system consists of two separate modules: one for the design knowledge management system that captures information related to product design and design standards, and the other for manufacturing knowledge management to capture process and resource related knowledge. The primary action of the workflow is to activate processes, for example assigning a design task to connect with the KBS. All the information or relevant knowledge is stored and retrieved via a PLM data repository. The PLM data repository is used to store product centric information and provides a method of locating information within the PDM system. The second stage of the workflow is to assign a concurrent task which involves notifying the development team and issue requests to the appropriate personnel to enter conceptual design data. The third stage of the workflow is to review the conceptual design.

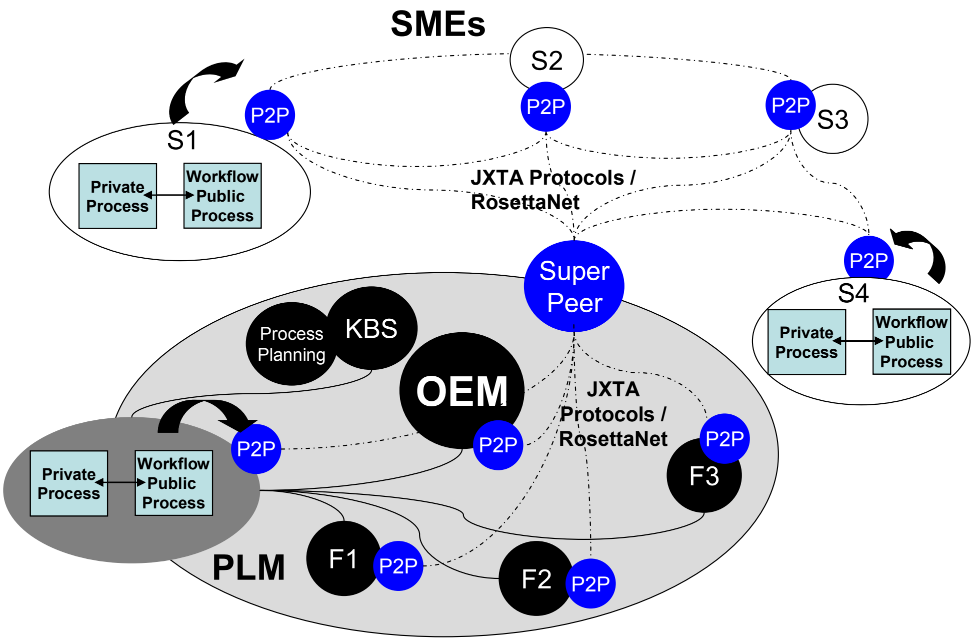
The fourth stage is an XML parser mechanism which supports the interaction of data reused by the CAPABLE and PLM systems. The purpose of the CAPABLE system is to allow alternative process plans (or routings) for custom parts to be generated, evaluated and improved based upon estimated *manufacturability* before committing to a fully specified product model and supplier. The XML parser is responsible for extracting manufacturing knowledge from the XML formatted knowledge file to be reused by the process planning engine in the CAPABLE system. With the attachment of updated historic information and manufacturing knowledge, a new product definition will be generated. The product definition will be delivered to the CAPABLE system to obtain preliminary process plans. The new process plans (routings) are then delivered to the PLM system for Plan/Review. The final stage involves capacity planning and implementation.

3.2 Infrastructure of the Peer-to-Peer Framework

Figure 5(a) illustrates the infrastructure of the configuration and characterisation of the product development collaboration processes between SMEs and OEMs or other larger organisations. S1, S2 and S3 represent SMEs in the framework. In the OEM representation schema, F1, F2 and F3 are the internal functions or divisions of the organisation, for example, product design, process planning to marketing. A process planning system and a KBS are used examples of different type of software deployed within the OEM via the PLM system. The PLM system used by the OEM is located within its own sub-network.

The framework is established using the basic infrastructure of the links using *hybrid* P2P networking (Fiorano Software, 2003), JXTA communication protocol and *RosenettaNet*. In a hybrid P2P system, the information is exchanged through a local *central server* (SuperPeer nodes). The SuperPeer node acts as a monitoring agent for all the other peers within its sub-network and ensures information coherence. The basic infrastructure builds on already available *open source* P2P solutions. A workflow technique is deployed to have better control of data and file sharing in order to distribute information to the right people, at the right time. Information requirements are set out during task delegation throughout the product development processes.

(a) Inter-enterprise collaboration using P2P



(b) Alternative Configuration of Inter-enterprise collaboration using P2P

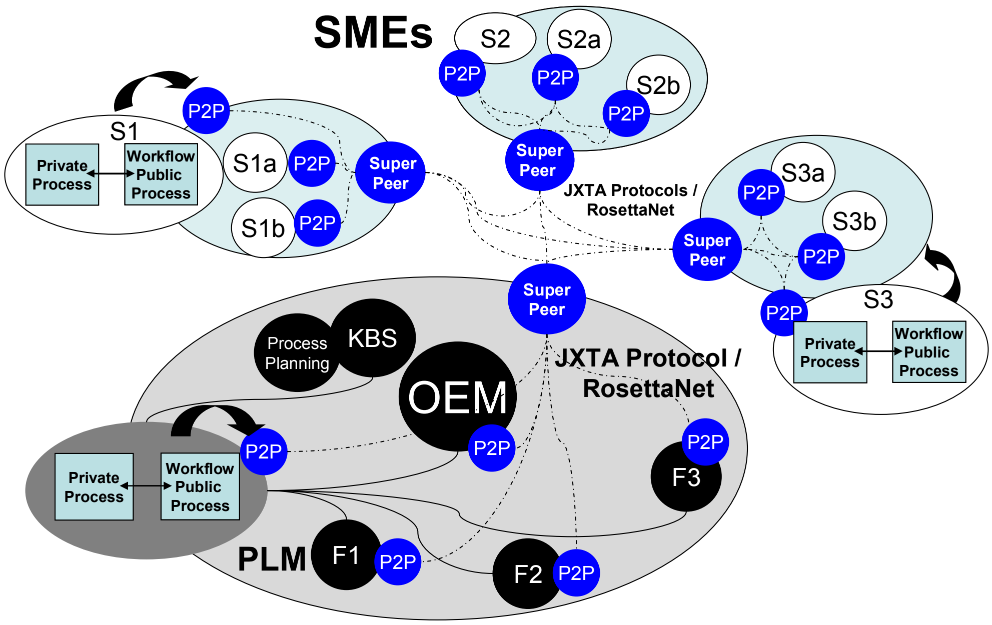


Figure 5: Configurations of P2P Infrastructure in Inter-enterprise Collaboration

The P2P nodes, illustrated in the diagram, act as gateways controlling information access. Connectivity is achieved using an open source implementation of JXTA.

Implementation of JXTA is in standard Java 2. The user functions of JXTA include the following:

- user interface queries,
- project management of collaborative groups, and
- group chat and instant messaging.

The choice was made partly for the security aspect, but also because JXTA implements a unique but anonymous identification mechanism for peers and rendezvous peers. Rendezvous peers can act as managers for peer groups and store the peer advertisement for the group for distribution to other P2P networks. Additionally, the system does not require a static network, but supports dynamic network architectures including the ability for individual users' to work offline which cannot be done with web-based systems. Figure 5(b) shows such an alternative configuration of the framework using SuperPeer nodes for communication connectivity. S1 consists of two subdivisions represented by S1a and S1b which form their own *peergroups*. Similarly, S2 and S3 are both have the same configurations.

3.3 Distributed Workflow in P2P Framework

Frequently process workflows are distributed collections of activities that involve groups of individuals at disparate locations. To coordinate these tasks, a process support system must provide for distributed process execution and integration with tools across networks. Traditional workflow adopts a centralised client/server approach to enact processes such as the native workflow function provided by the PLM system for the OEMs. For a decentralised network this research uses RosettaNet Partner Interface Processes (PIPs) to implement workflows (Yendluri, 2000). Figure 6 depicts the solution for distributed workflow for SMEs and OEMs collaboration. The use of

WebLogic Integration (Yendluri, 2000) implements standard RosettaNet PIPs through public (or collaborative) workflows. A public workflow provides the interface to other collaborative partners, while private workflows are used to interface to back-end systems in order to generate and respond to messages. Figure 6 also shows the process by which PIP workflows pass messages between collaborative partners. In figure 6, for example, the RosettaNet-oriented workflows process messages as follows:

1. SME1's private workflow initiates a RosettaNet message. Data is retrieved and formatted into a RosettaNet message structure, the appropriate PIP is determined, and the message is forwarded to the public workflow that implements the SME1's in the PIP.
2. The public workflow process creates the appropriate RosettaNet message. The message is sent to the public workflow of the OEM.
3. The OEM's public workflow receives the message, processes the header information, and then passes validated customer information and message content to the appropriate private workflow process.
4. The OEM's private process resolves message content and generates a reply. The reply is processed into a RosettaNet message structure and passed back to the OEM's public process.
5. The OEM's public process creates a RosettaNet reply message and sends it to SME1's public process.
6. The SME1's customer public process receives the reply message, processes header information, and then passes validated OEM's information and message content to the appropriate private process.
7. The private process resolves content of the reply message.

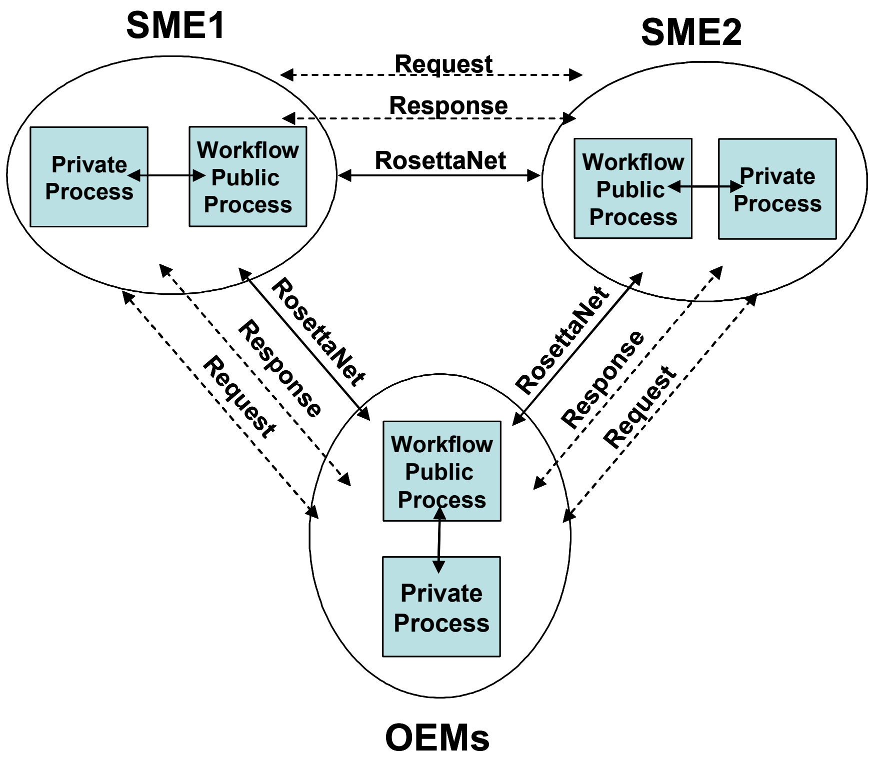


Figure 6: Distributed Workflow Diagram for SMEs and OEMs Collaboration

3.4 The 2-tier Communication Architecture in P2P Networking

There are several different P2P communications protocols available, the most common ones are JXTA (Gong, 2002), Napster, Gnutella and AIM (Leuf, 2003). The applications of these protocols for peer-to-peer systems are usually designed for delivering a single type of network service, for example, Napster for music file sharing, Gnutella for generic file sharing and AIM for instant messaging. For implementation purposes, JXTA was adopted as the protocol for the framework because it is XML-based and open source. It was initiated and developed by Sun Microsystems, Inc, with the intention to standardise this technology for peer-to-peer networking. JXTA is a set of networking protocols similar to HyperText Transfer Protocol (HTTP) (http://www.w3.org) and TCP/IP (http://www.protocols.com). The JXTA layer sits between the networking stack and the application stack, handling peer-to-peer communication. The JXTA platform standardizes the manner in which peers:

- Discover each other,
- Advertise network resources,
- Communicate with each other, and
- Cooperate with each other to form secure peer groups.

The framework described in this paper uses the two-tier solution shown in figure 7, which enables enterprises to establish connections between them in real-time. The first layer uses the JXTA communication protocol for XML-based messaging as well as the "P2P" nodes connectivity. The second layer uses RosettaNet for distributed workflow and XML-based Electronic Data Interchange (EDI).

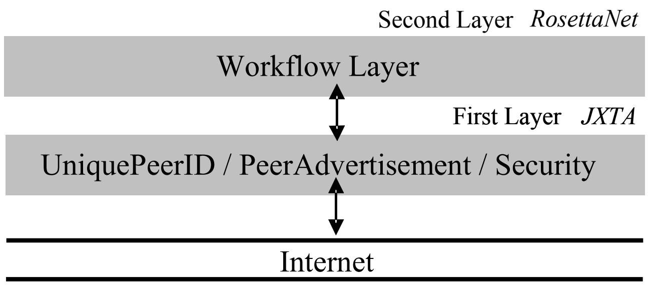


Figure 7: The 2-tier Communication

3.5 Security Issues in P2P Networking

Security is one of the main challenges in implementing P2P due to the lack of a centralized control server. Current P2P applications are designed mainly for home users to file share music and movies. These applications are not implemented with information security and offer no encryption for sensitive information. To address the security issues, Sun Microsystems created an infrastructure called Project JXTA, which allows programmers to use a common library when creating new P2P applications, by providing a robust, secure, interoperable applications programming interface (API). One of the security features in JXTA is the implementation of *AuthenticationCredential* which allows users or peers to join a *peergroup* after a set of credentials have been verified. *AuthenicationCredentials* are used by JXTA Membership Services as the basis for applications for *peergroup* membership. The *AuthenticationCredential* provides two important pieces of information:

- the authentication method being requested
- Identity information which will be provided to that authentication method.

Furthermore, JXTA also provides developers to implement *PasswdMembershipService* which allows a Membership Service based on a password scheme.

4. RESULT OF CASE STUDIES

The case studies were carried out in single user access environment, however, the architecture also supports multi-user access using PLM and P2P technologies. As discussed in Section 3, PLM allows simultaneous reading and writing of the same data in the repository, thus, supporting concurrent engineering practices. This is done by locking parts or the entire database while the data are being updated. Furthermore PLM supports access authorizations and hence data inconsistencies can be avoided and relationships such as the structure between data are maintained. As in the P2P application, connectivity is supported by individual super-peer node and hence the multi-user functionality is one of the main strengths of the architecture.

4.1 Case Study 1 – a Centralised Collaboration in Product Development

Mabey & Johnson (UK) Ltd manufactures steel panel bridges for rapid assembly on-site. The bridge system relies on the use of standardised components (‘Bailey’ bridge panels), which are joined together in the desired configurations. The problems faced by the personnel at the company include:

- The links between the design and manufacturing offices are very weak. Designers are primarily structural engineers who do not have access to manufacturing knowledge in order to improve the ease of manufacture of their designs.
- Engineering changes are processed manually and involve interlinked stages between different company sites. Once changes are made to a design and manufacturing plans, it is difficult to ensure that the knowledge stored in a digital format which is accessible to the personnel making future design and manufacturing decisions.

The company has created some applications to link the design and manufacturing processes within the ERP system. However, many shortfalls remain with the methods applied, and these include:

- A lack of workflows to automate the process of managing documents, project sequences and engineering change / revision control.
- A lack of interaction between different departments, namely between the marketing, engineering and manufacturing sectors of the business.
- There is no framework or technology to store and reuse the natural-language knowledge associated with the company's products, activities and user experiences.

To alleviate this situation, this research has proposed the application of the centralised 'out-of-box' solution. The centralised testing environment is illustrated in figure 8 which depicts an example of web-based data interoperability between the knowledge-based system, the aggregate process planning system, the PLM and ERP systems. The methods and tools have been used to generate a preliminary process plan for a single Bailey bridge panel. The example shows that the captured knowledge will be saved in a XML file into a PLM data repository. The illustration also shows the main implementation of the software components which depicts the links of a knowledge-based system to be re-used by the CAPABLE system. The links were established by the

XML-parser. Thus, this allows the extracted data to be transferred to the data models in the CAPABLE system.

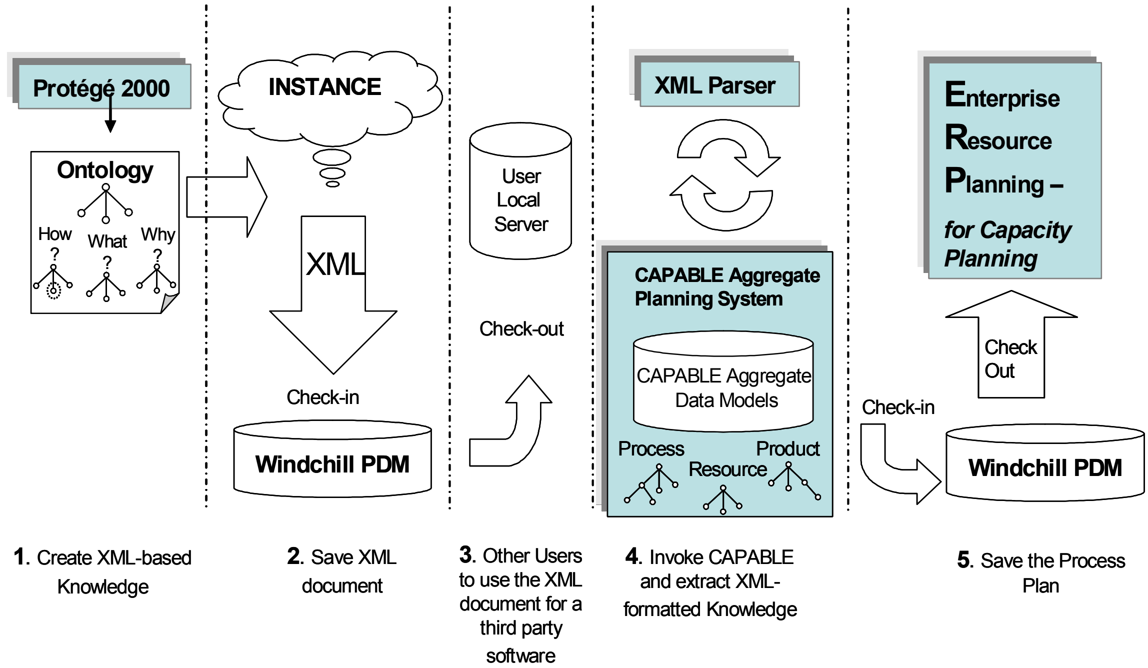


Figure 8: Centralised Testing Environment

Figure 9 (a), (b), illustrates the knowledge statements related to a specific object termed Robot_Cell_0 which belongs to a station of a factory. As it highlighted in the diagram, when the XML Parser is invoked within the factory resource model of the CAPABLE System, the knowledge statements will then attach to a particular group of machines which can be used for further analysis to enhance the planning process of a product. The example shown in figure 9 (c) indicates the resulting knowledge statements extracted to the CAPABLE System which relate to a factory (resource) model object 'Galvanising Trailer' which belongs to a cell of "M&J (UK) Ltd" factory. The design engineers are then required to select the relevant knowledge to refine the design and subsequently to run the CAPABLE system to obtain a preliminary process plan based upon these knowledge factors. If the plan requires review, the prioritised knowledge factors, obtained from capability analysis, highlights the most appropriate areas of the process plan for improvement based upon the specific instances of knowledge factors used. If the process plan is acceptable, it is then delivered to the PLM system for Plan/Review, and subsequently is readied for implementation in an ERP System for capacity requirements planning.

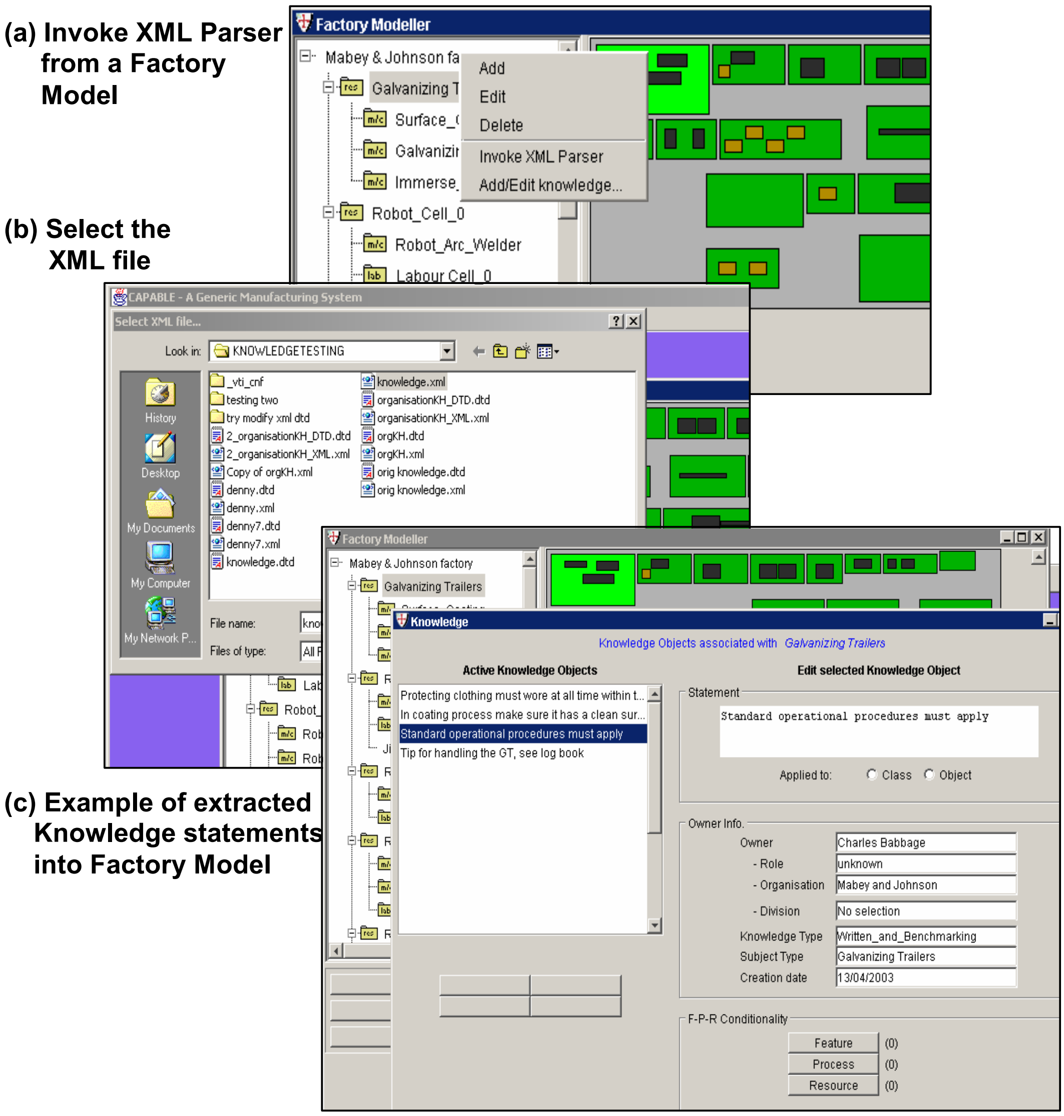


Figure 9: Example knowledge statements related to a specific object

4.1.1 Closing Remarks of Case Study 1

In the current way of doing business within M&J (UK) Ltd., a significant amount of the technical knowledge is tacit and possessed by experts. However, the methodology demonstrated in this research was used to store and re-use this knowledge within the process of collaborative product development. According to the industrial collaborator:

- Early collaboration in product design using this methodology can maximise the opportunity for optimising designs
- With the increasing level of captured knowledge in product design and manufacturing capabilities, it can prevent poor decision making and enable the design to be right-at-first-time.
- Accelerate the feedback and amount of relevant available information when designing customised products is enhanced
- The amount of lead time that can be reduced for new product introduction is difficult to measure at this stage as the methodology only tested the early stages of the product development process.

These observations support the initial hypotheses that the centralised collaboration streamlines the product development process and reduces design rework due to poor initial decision making.

4.2 Case Study 2 - Utilisations of a De-centralised Network in Product Development

ArvinMeritor Automotive is a large Tier-1 automotive supplier. This company is a global enterprise with different subsidiaries based primarily in the US, UK, mainland Europe and China. The applications of P2P address the needs of de-centralised organisations to collaborate and share knowledge regardless of geographical location. One of the main reasons to use this case study is that majority of the industrial collaborator's design is outsourced to local suppliers. Apart from the interest of utilizing PLM technology to enhance design knowledge, the industrial collaborator is also interested in adopting a decentralised network to do business with smaller companies.

Figure 10 illustrates the topology of the system. In this instance the architecture was set up with a super-peer network in order to create a number of virtual servers at each of the project’s participants sites. These super peers are visible as peers to both the other super-peers and the internal peer-net which they serve. They also act as the default rendezvous peer, and peer information is shared between the super-peers in order to improve the redundancy and query speed of the system. The grey area contains the internal peer-net of the enterprise with the interconnected PLM and knowledge-based system servers and workstations. Outside the peer-net is the external peer-to-peer environment which interlinks all the super-peers from every collaborator together. This enables peers to connect to each other enabling queries for and manipulation of knowledge on different peers on the internal and wider peer-net transparently.

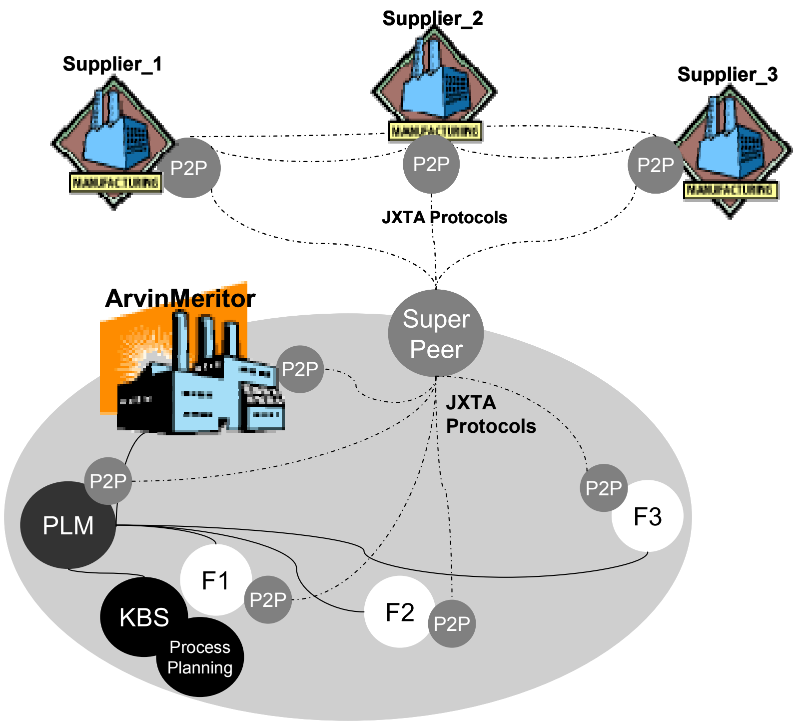


Figure 10: Super peer architecture showing the interacting within internal and external peer nets of a collaborative project.

Figure 11 illustrates the JXTA user interface. The right-hand window shows the user interface from where queries, project management of collaborative groups and widely used items such as group chat and instant messaging are readily implemented by the JXTA protocol. The systems' settings enable enterprises and users without static addresses (or static network architectures) to collaborate using dynamic addressing, and this flexibility, as well as the users' ability to work offline, empowers users in all possible circumstances.

Figure 11: JXTA configuration window and user interface

The main objective of this case study was to demonstrate the application of a centralised PLM, decentralised P2P and SuperPeer production networks scenarios through the comparisons of the following features:

- *Time of deployment*. The time to customise and deploy the entire project including the project management framework and communications setup.
- *Virtual Enterprise setup*. How rapidly could VE be set up and start to operate on all the remote sites.
- *Deployment of ontology-based KBS*. How easy was it to enter, query, and reuse both the ontology and domain knowledge within the collaborative group.
- *Lifecycle Management*. The ability to control the state of a document, manage versioning and history of the data.

- *Total cost of ownership*. The costs of licences, implementation, system integration, training and maintenance.

The case study was empirically based using a small inter-enterprise setup. The server was located in the academic research laboratory, and users concurrently created the new project, generated new concepts and optimised the design gradually from two remote locations to simulate the collaborative scenario as shown in figure 10. All KBS deployed SAP-DB, a commonly shared back end. The applications were tested on identical hardware with identical configurations and internet connections. The apparatus were Dell Xeon workstations with 1GB RAM, 15K rpm disks and 1MB internet connection, the operating system was Windows 2000 on all machines. A 1 MB internet connection was used to minimize the cost of bandwidth, thus, demonstrating one of the advantages of decentralised network application. The test simulated a small scale virtual enterprise (VE) setup through from initiating the VE to running the system within the collaborative network. This setup has a typical VE with a large number of small servers distributed within a common network, with a small number of transactions are processed at each node. Table 1 show the results based on the comparison of key features requisite for a collaborative project environment.

Application	Time of Deployment	Virtual Enterprise setup	Deployment of Ontology-based KBS	Lifecycle management	Total cost of ownership
Commercial PLM	1 month for small project.	B2B* one-to-many integration, manual	RDFs† ontology in document container, access via PLM	Graphical workflow	Server & client licence, implementation and maintenance
Pure P2P	1 day	Peer to peer, automatic discovery	RDFs ontology in java application	Version control and rule based system	Training on P2P and knowledge app
SuperPeer net	1 day	SuperPeer automatic discovery	RDFs ontology in java application	Version control and rule based system	Training on P2P and knowledge app

Table 1: Comparison of key features of tested system (Aziz et al, 2005)

4.2.1 Closing Remarks of Case Study 2

PLM systems are inherently centralised, complex to set up and require a long period of time for customisation. Conversely, the RosettaNet standard, implemented in the PLM system, can decrease the amount of customisation needed, but not eliminate it as RosettaNet only provides a subset of the messaging and data models of the inter-enterprise link. Unlike the 2-tier communication system as shown in figure 7, a PLM's data model and workflows are neither portable nor standardised. The data model can be modified by an expert who has to model, program, compile, update the database and integrate the code into the PLM system before it can be used. The costs of implementation, licences and maintenance are overly expensive and only practical when the enterprises involved can share the cost between each other over a long period of collaboration.

* Business to Business- www.b2btoday.com
† Resource Description Framework - www.w3.org/RDF/

The application of P2P and open standards to support a VE can fullfield the following requirements:

- Elimination the interoperability issues for product and project knowledge, enabling small enterprises to implement application standards such as STEP-PDM, and easier set up for inter-enterprise collaboration,
- Elimination of centralised bottlenecks in bandwidth and resources, empowerment of collaborators within networks to control the knowledge they create, solving the management of intellectual property rights within virtual enterprise, and
- Elimination of centralised administration that results in reduction in cost and complexity and enables domain professionals to tailor the system.

In addition, *open source* can significant reduce software licence costs, provide a solution to the problem of *vendor lock-in* in the long term, elimination of unnecessary complexity and freedom to modify the application. *Open Source* also provides platform and application independence. This enables the enterprise to concentrate on its work and not be tied in to any vendor, the rapid and complete migration from the proposed system to future applications, and empower the enterprise to leverage its existing investments.

5. CONCLUSIONS

Different paradigms have been proposed to support distributed network environments during the mid 1990s through to the early 2000s. Since then, Web-based technologies and data exchange formats have matured. With the availability of enterprise integration systems and *open source* technology, this research has proposed and developed a different approach. Hence, the deployments of an ‘out-of-box’ solution which provides a standardised framework with centralized and de-centralized concepts to support production networks in design and manufacturing. In this research work, the discussions have been focused on the proposal of the integration architecture to support a collaborative product development and knowledge distribution method in the early stages of the product development process. However, the infrastructure of the integration architecture is also relevant to the later stages of product development, providing that suitable software systems are used which can exploit XML based information.

Case study 1 described the testing of a centralised product development integration architecture which demonstrated the advantages of the applications of web-based technologies for enterprise integration systems into the industrial collaborator's product development process. Case study 2 described the testing of the combination of decentralised and centralised production networks using P2P technologies. The study focused on creating a virtual enterprise collaboration to compare the applications of a centralised PLM, pure P2P and SuperPeer.

6. FUTHER WORK

In terms of future work, one specific issue is the upgrading of a new data exchange mechanism in the integration architecture. An RDF parser, which is an advanced version of the XML-parser, is under development in the Web-based technologies community. The RDF parser is designed to run in a Web-browser which can be used to extract information from both XML and RDF based documents on the client side. As the XML parser only deals with the syntax, the RDF parser will deal both the syntax and semantics used in the design and manufacturing knowledge. However, as far as the authors are aware, during this period of the research the support for RDF parsers in the

W3C (World-Wide-Web Consortium) has not been fully completed yet. As for future work, the research will investigate and upgrade the application of RDF parser into the product development integration architecture.

A new project is under development in *open source* PLM (Salustri, F., 2006). The Opensource PLM (OPLM) project aims to provide SMEs with the ability to perform the needs of current proprietary PLM functions, but, freely available without the prohibitive resource requirements of the larger systems. In the future version of the proposed architecture, further investigation will be carried out to integrate with this new open source PLM when it is available.

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